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C-183

[redacted]

CONFIDENTIAL

FILE;

[redacted] 25X1

[redacted] 25X1

15 FEBRUARY 1961

SECRET

[redacted] 25X1

DEAR FRANK:

REFERENCE IS MADE TO CONTRACT 603.

WE ARE ENCLOSING HEREWITH TWO (2) COPIES OF PROGRESS REPORT ON THIS CONTRACT.

VERY TRULY YOURS,

[redacted] 25X1

VICE PRESIDENT

DLC:G

2 ENC.

REGISTERED MAIL
RETURN RECEIPT
REQUESTED.

SECRET

[redacted] 25X1

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PROGRESS REPORT

ON

CONTRACT NO.603

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PROGRESS REPORT

[redacted]

25X1

FOR THE PERIOD ENDING JANUARY 18, 1961

This has been a period of continued effort to produce a satisfactory design for the electrostatic switch. A number of switches have been constructed during this period and have been found to operate quite successfully. The final design, as well as various construction problems and methods, will be discussed in the following report.

Preliminary tests indicate that these models will exhibit the desired physical and electrical characteristics which have been outlined in previous reports. To achieve a design that satisfies all of the requirements it has been necessary to carefully select those characteristics which represent the best compromise of capacity, size, operating potentials, geotropism, shock resistance, etc.

Two basic types of structures were considered during the initial investigations of this project, the cantilever and the torsion bar. Both are well known and both widely used. The final selection for the switch mechanism was the torsion fiber type, however, much of the experimental data included in this report was obtained from models of the cantilever type. The cantilever beam is a simple mechanism to construct as well as simple to calculate.

The basic structure of the switch (fig. 1) consists of a torsion fiber supported at both ends in a suitable mounting frame.

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ATTACHED TO THE CENTER OF THE TORSION FIBER IS A CONDUCTING CROSS BAR. THE ELECTRICAL CIRCUIT (FIG.2) FROM THE LOAD BATTERY IS THUS COMPLETED THROUGH THIS CROSS BAR.

LOCATED NEAR EACH END OF THE CROSS BAR IS AN ELECTROSTATIC PLATE WHICH IS CONNECTED TO THE CHARGING BATTERY. THERE WILL NOW EXIST, DUE TO THE CHARGING BATTERY POTENTIAL, AN ELECTROSTATIC FORCE BETWEEN THE CROSS BAR AND PLATES. THIS IS A FORCE OF ATTRACTION SUCH AS TO PRODUCE ANGULAR ROTATION OF THE TORSION FIBER. THIS ROTATION CONTINUES UNTIL EQUILIBRIUM IS ESTABLISHED BETWEEN THE ELECTRIC FORCES AND THE OPPOSING FORCES DUE TO TWISTING OF THE TORSION FIBER. THE POSITION OF THE CROSS BAR WHILE THE SYSTEM IS IN THE CHARGES CONDITION INTERUPTS THE ELECTRICAL CIRCUIT FROM THE LOAD BATTERY. REMOVAL OF THE ELECTROSTATIC FORCE, BY DISCONNECTING THE CHARGING BATTERY WILL ALLOW THE ELASTIC RESTORING FORCES OF THE TORSION FIBER TO AGAIN COMPLETE THE CIRCUIT.

IT SHOULD BE NOTED THAT A STRUCTURE OF THIS TYPE CAN BE GIVEN DYNAMIC AS WELL AS COMPLETE STATIC BALANCE, THEREBY PROVIDING ALMOST COMPLETE RESISTANCE TO SHOCK, VIBRATION, GEOTROPISM AND TILT. THE COMPLETE SWITCH ASSEMBLY IS SHOWN IN (FIG.3). THE TIE BARS WHICH SECURE THE ASSEMBLY ALSO SERVE AS ELECTROSTATIC ATTRACTING PLATES. ADDITIONAL FORCE AND GREATER ANGULAR DISPLACEMENT IS OBTAINED BY THE USE OF TWO CROSS BARS.

THE FOREGOING DISCUSSION IS BASED ON THE FUNDAMENTALS OF THE MECHANISM ONLY, WITHOUT REGARD FOR SUCH IMPORTANT DETAILS AS RESISTIVITY, FORCE MAGNITUDES, ELASTIC COEFFICIENTS AND OTHER FACTORS WHICH INFLUENCE THE OPERATION OF THE SWITCH.

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CHARACTERISTICS WHICH ARE NORMALLY IGNORED OR AT LEAST TAKEN FOR GRANTED WITH ORDINARY DEVICES BECOME EXTREMELY IMPORTANT WHEN THE SMALL PHYSICAL DIMENSIONS OF THE SWITCH ARE CONSIDERED. THESE DIMENSIONS HAVE NOT BEEN AN ARBITRARY CHOICE, BUT ARE DICTATED PRIMARILY BY THE OPERATING POTENTIALS WHICH CAN BE SAFELY APPLIED TO THE CHARGED SYSTEM. POTENTIALS IN EXCESS OF 300 TO 400 VOLTS APPLIED TO THE STORAGE CONDENSER INCREASE THE PROBABILITY OF DIELECTRIC BREAK-DOWN AND ELECTRICAL LEAKAGE.

WITH AN APPLIED POTENTIAL OF SAY 400 VOLTS, THE ELECTROSTATIC FORCE PRODUCED IS EXTREMELY MINUTE, AND CAPABLE OF DEFLECTING FIBERS OF ONLY VERY SMALL DIMENSIONS. A QUARTZ TORSION FIBER WHOSE ELASTIC FORCES ARE COMPARABLE TO THE ELECTROSTATIC FORCES INVOLVED WILL HAVE A DIAMETER OF ONLY 3 OR 4 MICRONS.

IT IS THESE EXTREMELY SMALD DIMENSIONS AND MINUTE FORCES WHICH INTRODUCE SEVERAL PROBLEMS OF GREAT IMPORTANCE, PARTICULARLY THE PROBLEMS PERTAINING TO ELECTRICAL CONTACTS OPERATED AT SUCH SMALL CONTACT PRESSURES.

QUARTZ, WHICH IS AN EXTREMELY GOOD INSULATOR, IS USUALLY GIVEN A CONDUCTING COATING OF SOME TARNISH FREE MATERIAL SUCH AS PLATINUM OR GOLD, FOR THOSE PORTIONS OF THE SYSTEM WHICH MUST CARRY CURRENT.

THIS COATING IS APPLIED BY MEANS OF VACUUM DEPOSITION. A SPUTTERING PROCESS BEING THE MOST SUITABLE FOR PLATINUM. WITH FIBER DIAMETERS OF ONLY A FEW MICRONS A VERY LIMITED DEPOSTT OF PLATINUM IS POSSIBLE. A FEW MOLECULAR THICKNESSES BEING TYPICAL.

CONSIDERING THE TOTAL LENGTH OF THE CONDUCTING PATH, IN ADDITION TO THE SPREADING RESISTANCE AROUND THE SMALL AREA OF

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ACTUAL CONTACT, THIS REPRESENTS A MINIMUM CONTACT RESISTANCE OF SEVERAL THOUSANDS OF OHMS, WHICH ESTABLISHES A DEFINITE LIMIT TO THE AMOUNT OF CURRENT WHICH CAN BE HANDLED.

BETWEEN TWO SURFACES IN CONTACT ONLY A VERY SMALL PERCENTAGE OF THE AVAILABLE SURFACE IS IN ACTUAL CONTACT. THIS IS TRUE FOR BOTH STATIONARY AND SLIDING CONTACTS. THE FACT THAT MATING SURFACES ARE IN ACTUAL CONTACT AT ONLY A VERY FEW POINTS IS PROBABLY DUE TO ROUGHNESS OR IRREGULARITIES IN THE SURFACES.

THE ACTUAL AREA IN WHICH CONTACT TAKES PLACE IS CONTROLLED BY THE FORCE APPLIED, ALL OTHER THINGS BEING EQUAL.

THE LINE OF CURRENT FLOW IN TWO CONTACTS MEETING AT ONLY ONE ACTUAL POINT ARE THUS CONSTRICTED TO PASS THROUGH THE ACTUAL CONTACT AREA, AND SPREAD APART AGAIN ARTER SUCH PASSAGE, TO DISTRIBUTE THEMSELVES EVENLY OVER THE CONTACT CROSS-SECTION. THUS, THE CURRENT IS FORCED TO TRAVEL PATHS WHICH ARE LONGER THAN THE THICKNESS OF THE CONTACTS. SINCE THE RESISTANCE OF A WIRE IS PROPORTIONAL TO ITS LENGTH IT WILL BE SEEN THAT THE INCREASE OF THE LENGTH OF THE CURRENT FLOW LINES INTRODUCES EXTRA RESISTANCE (SPREADING RESISTANCE) TO THE PASSAGE OF CURRENT. TO THIS MUST BE ADDED THE RESISTANCE OF ANY FILM WHICH IS PRESENT AT THE FACES OF THE CONTACTS.

AN EVEN MORE SERIOUS LIMITATION TO THE CURRENT CARRYING CAPABILITIES IS THE PHENOMENA OF CONTACT WELDING AND MATERIAL TRANSFER. VOLTAGE AND CURRENT ARE CLOSELY RELATED IN THE PERFORMANCE OF ELECTRICAL CONTACTS. IT IS DIFFICULT TO CONSIDER EITHER VOLTAGE OR CURRENT INDEPENDENTLY IN REGARD TO THEIR EFFECTS ON CONTACT OPERATION. FOR THE IMMEDIATE DISCUSSION ONLY DIRECT CURRENT CIRCUITS CONTAINING ONLY PURE RESISTIVE ELEMENTS WILL BE CONSIDERED.

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In DC circuits there are four different reactions that may take place when a current is being interrupted. One or more of these may be sufficiently pronounced to have a marked effect on the operation or life of the contacts. The four phenomena are:

(1) Low voltage phenomena

(2) Arc stage

(3) Gaseous discharge

(4) Spark discharge

Spark Discharge may occur between contacts if the voltage across the contacts exceeds the minimum breakdown voltage of the air gap (approx. 320 to 350 volts). When this voltage is exceeded, the gap between contacts becomes conducting and a high energy discharge may occur.

As the potential rises between separated contacts, the gaseous space between the contacts contains carriers of electrical charge. A current may then flow through the contact gap.

In both spark and gaseous discharges, sufficient heat is generated by positive ion bombardment to vaporize the negative contact material. This vaporized material then condenses on the cooler positive contact, thereby producing positive material transfer. In addition, the large mount of energy expanded between the contact points will tend to oxidize the contact surfaces.

Obviously, high voltage operation is out of the question here. Such operation would invariably result in total contact destruction.

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WITH LOW VOLTAGE PHENOMA, AS THE CONTACTS BEGIN TO SEPARATE, THE DECREASE IN CONTACT PRESSURE CAUSES AN INCREASE IN CONTACT RESISTANCE. THE LAST POINT OF CONTACT IS HEATED SUFFICIENTLY TO FORM A MOLTEN PARTICLE OF METAL, THUS FORMING A BRIDGE BETWEEN THE CONTACTS. AS THE CONTACTS SEPARATE FURTHER THE MOLTEN METAL WHICH FORMS THE BRIDGE WILL COLLAPSE AND DEPOSIT METAL ON BOTH CONTACTS. THIS ACCUMULATION OF METAL WILL FORM AN APPRECIABLE NEGATIVE MATERIAL TRANSFER.

AN ARC WILL FORM BETWEEN SEPARATING CONTACTS PROVIDING CERTAIN MINIMUM VALUES OF VOLTAGE AND CURRENT ARE EXCEEDED. THE CHARACTERISTIC OR MINIMUM ARC VOLTAGE OF A MATERIAL IS DEFINED AS THE LOWEST VOLTAGE AT WHICH AN ARC WILL FORM BETWEEN CONTACTS OF THIS MATERIAL AT ATMOSPHERIC PRESSURE.

THE VALUES ARE DIFFERENT FOR VARIOUS MATERIALS, BUT FALL IN THE RANGE FROM ABOUT 9 TO 20 VOLTS. A TYPICAL VALUE FOR PLATINUM IS APPROXIMATELY 16.0 VOLTS AND FOR GOLD 15.0 VOLTS.

IN ANY CIRCUIT WHERE THE VOLTAGE APPLIED TO THE CONTACTS IS BELOW THE MINIMUM ARCING VOLTAGE THE ARCING CURRENT VARIES WITH THE KIND OF CONTACT MATERIAL.

FROM THE FOREGOING DISCUSSION IS IS QUITE CLEAR THAT THE CONTACTS MUST BE OPERATED AT NOT ONLY LOW VOLTAGE, BUT ALSO LOW CURRENT, SHOULD THE CONTACTS SHOW A TENDENCY TO STICK OR WELD, FOR ANY REASON WHATSOEVER, THE SMALL FORCES WHICH ARE AVAILABLE TO SEPARATE THEM WOULD BE UNABLE TO DO SO.

IF THE CONTACTS BECOME TARNISHED ADDITIONAL CONTACT RESISTANCE WILL BE ENCOUNTERED. CONTACTS MAY BECOME COATED WITH FILMS OF OXIDE, SULPHIDE, OR COMPLEX CHLORIDES OR SULPHATES.

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SUCH FILMS HAVE HIGH SPECIFIC RESISTANCES. THE EFFECT OF TARNISH FILMS ON CONTACT RESISTANCE IS MORE NOTICEABLE BETWEEN CONTACTS IN LOW VOLTAGE, LOW CURRENT CIRCUITS AND AT LOW CONTACT FORCES.

UNDER SUCH CONDITIONS THE FILM MAY COMPLETELY INSULATE ONE CONTACT FROM THE OTHER SO THAT NO CURRENT WILL FLOW. THE INSULATION EFFECT WILL PERSIST UNTIL EITHER THE VOLTAGE BETWEEN CONTACTS IS INCREASED SUFFICIENTLY TO RUPTURE THE FILM, OR THE FILM IS BROKEN BY ABRASION BY SLIDING OR WIPING BETWEEN THE CONTACTS.

A FIELD STRENGTH OF APPROXIMATELY 2×10^6 VOLTS/CM IS REQUIRED TO RUPTURE THE AVERAGE TARNISH FILM.(FIG. 4) SHOWS THE VOLTAGE REQUIRED TO PUNCTURE FILMS OF VARIOUS THICKNESSES.

ADEQUATE CONTACT FOLLOW THROUGH AND CONTACT PRESSURE IS PROVIDED FOR IN THE PRESENT SWITCH DESIGN BY GIVING THE TORSION FIBER A PRE-LOADING TWIST OF 90 DEGREES. THIS ASSURES ADEQUATE TENSION OF THE CONTACTS AGAINST THE CROSS BAR WHILE IN THE NORMAL OR CLOSED POSITION. PRECISE ADJUSTMENT OF EACH CONTACT IS MADE, DURING THE FINAL ASSEMBLY OF THE SWITCH, BY BENDING OF THE CONTACT SUPPORTS.

UNFORTUNATELY, THE LOW VOLTAGE REQUIREMENTS FOR NON-WELDING OPERATION IS IN CONTRADICTION TO THE VOLTAGE NECESSARY FOR GOOD FILM RUPTURE.

A PROBLEM OF EQUAL SERIOUSNESS AS THOSE ALREADY MENTIONED IS THE PROBLEMS ALWAYS ASSOCIATED WITH THINGS OF MICROSCOPIC DIMENSIONS. SMALL OBJECTS ALWAYS HAVE A TENDENCY TO STICK TOGETHER. THIS STICKINESS OR COHESION TENDS TO HOLD THE CONTACTS TOGETHER ONCE CONTACT HAS BEEN MADE. IT IS THIS MOLECULAR ATTRACTION PLUS ANY ATTRACTION CAUSED BY WELDING WHICH MUST BE

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OVERCOME BY THE ELECTROSTATIC FORCE ON THE CROSSBAR IN ORDER TO OPEN THE SWITCH.

LITTLE IS KNOWN ABOUT THE FORCES BETWEEN MOLECULES. IT IS THESE SAME INTERMOLECULAR FORCES WHICH ARE RESPONSIBLE FOR SURFACE TENSION, CAPILLARY ACTION, ABSORPTION AND MANY OTHER SURFACE PHENOMENA. THEY HAVE NEITHER BEEN DETERMINED EXPERIMENTALLY OR DEDUCED FROM THEORY. THEY ARE NOT, HOWEVER, THE CHEMICAL ATTRACTIONS OR VALANCE BONDS THAT LINK ATOMS IN COMPOUNDS.

RECENT INVESTIGATIONS INDICATE THE PROBABILITY THEY ARE INSTEAD LONG RANGE FORCES WHICH ARE PURELY ELECTROMAGNETIC IN NATURE AND, AS SUCH, DEPEND ONLY ON THE DIELECTRIC PERMEABILITY AND ABSORPTION SPECTRA OF THE CONTACTING MATERIALS.

IN THE CASE OF MICROSCOPIC SAMPLES OF MATTER THE FORCES DEPEND ON MANY OTHER FACTORS INCLUDING THE SHAPE OF THE BODY.

WHEN TWO SURFACES ARE SEPARATED BY A GAP MUCH SMALLER THAN THE WAVE LENGTHS OF THEIR MAIN ABSORPTION LINES, THE FORCE APPEARS TO VARY INVERSELY AS THE CUBE OF THE GAP WIDTH. WITH GREATER SEPARATIONS, THAT IS, GREATER THAN THE ABSORPTION WAVE LENGTH, THE FORCE THEN VARIES INVERSELY AS THE FOURTH POWER OF THE DISTANCE. THIS CORRESPONDS RESPECTIVELY TO THE INVERSE SEVENTH AND EIGHTH POWER LAWS LONG PREDICTED BY EARLIER THEORIES.

THE EFFECTS OF THE UNDESIRED FORCES MENTIONED ABOVE COULD BE GREATLY MINIMIZED IF IT WERE ONLY POSSIBLE TO OBTAIN A GREATER ELECTROSTATIC WORK FORCE. AN EXAMINATION OF THE BASIC EXPRESSION FOR ELECTROSTATIC FORCE SHOWS THAT AN INCREASE IN THE SYSTEM CAPACITY WOULD PROVIDE THIS DESIRED EFFECT AND COULD BE ACCOMPLISHED BY EITHER AN INCREASE IN SURFACE AREA OR BY INCREASED

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DIELECTRIC CONSTANT OF THE DIELECTRIC MEDIUM. AN INCREASE IN AREA WOULD ALSO INVOLVE AN INCREASE OF MASS, WHICH IS UNDESIRABLE, AS WELL AS IMPRACTICAL. HOWEVER, INCREASING CAPACITY BY MEANS OF THE DIELECTRIC OFFERS RATHER INTERESTING POSSIBILITIES.

WITH THE SWITCH IMMERSED IN HIGH VISCOSITY FLUID (FIG. 5) THE ANGULAR ROTATION OF THE TORSION BAR INCREASES IN DIRECT PROPORTION TO THE INCREASE IN DIELECTRIC CONSTANT. IN ADDITION TO THE GAIN IN WORK FORCE, THE VISCOUS DAMPING PROVIDED BY THE FLUID GIVES THE UNIT ALMOST COMPLETE IMMUNITY FROM SHOCK AND VIBRATION.

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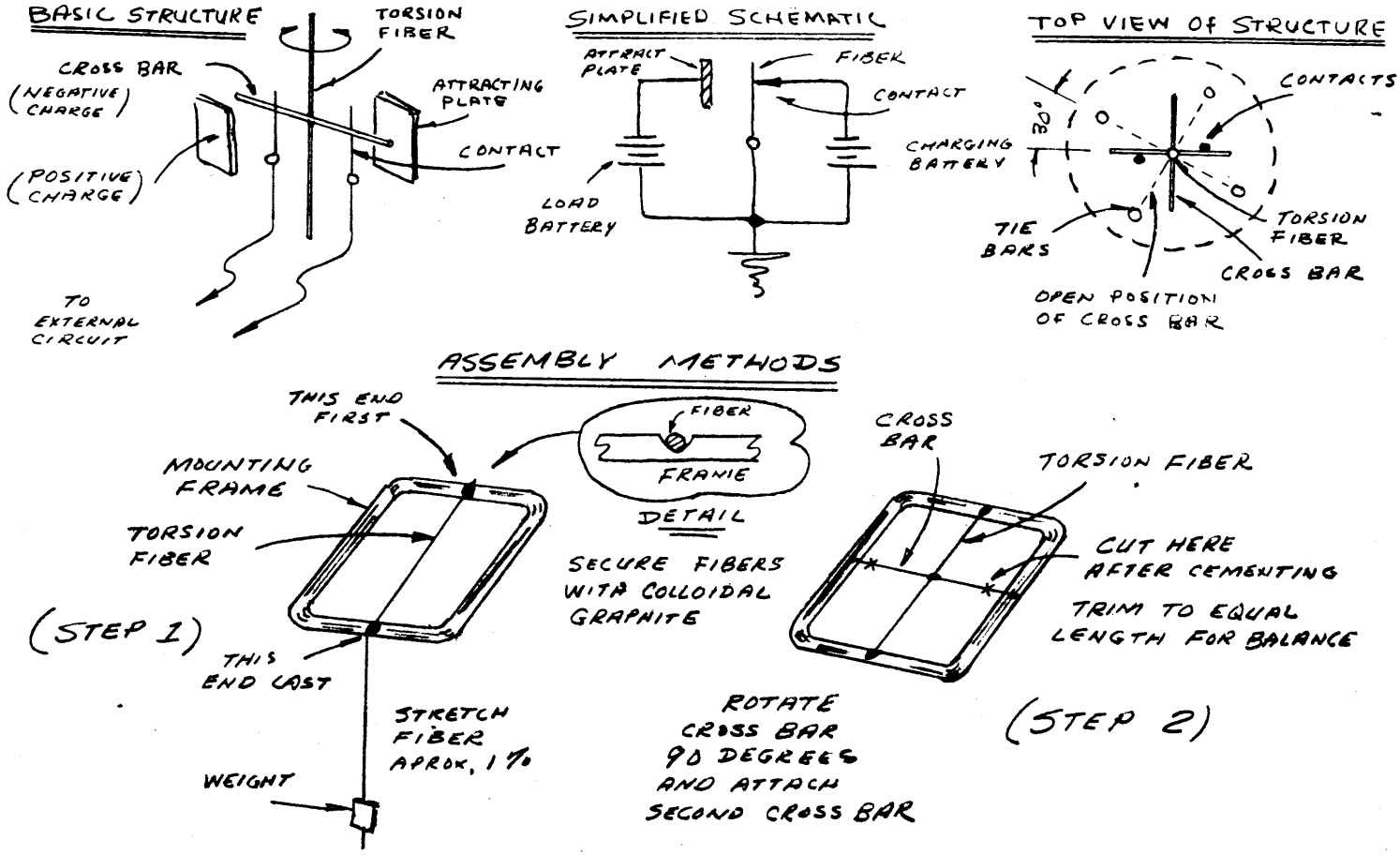
QUARTZ FIBER SWITCH MECHANISM Fig. 1



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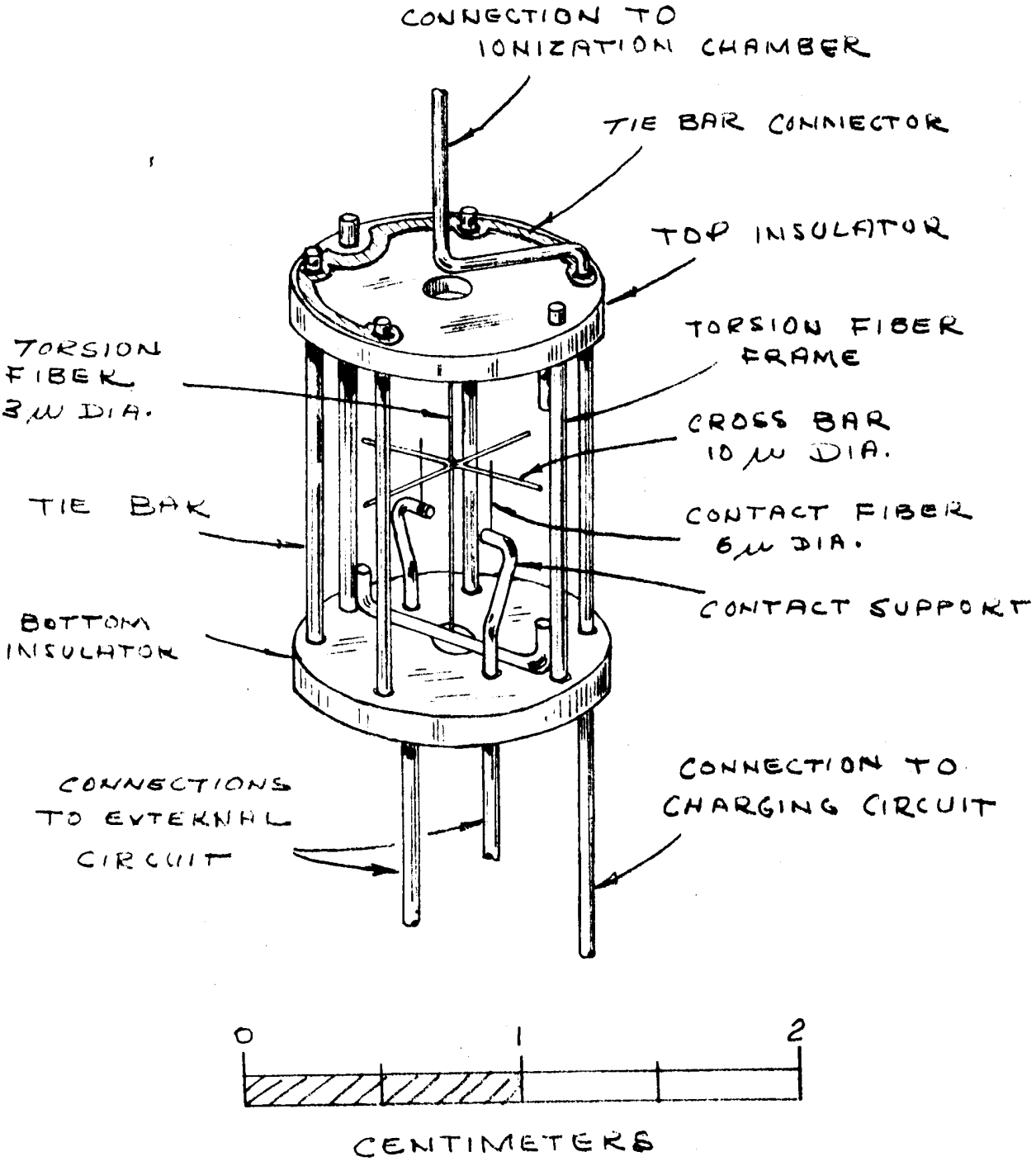
ELECTROSTATIC SWITCH FIG. 2



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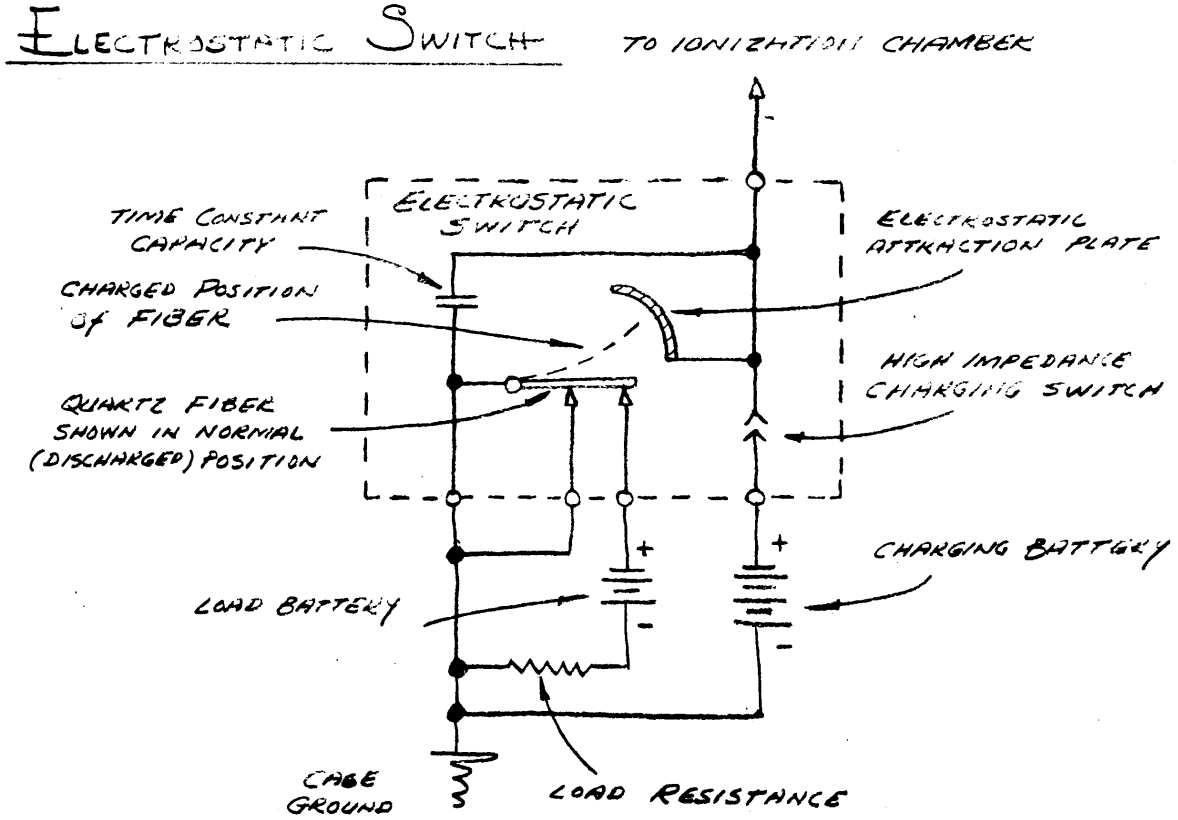

SCHEMATIC DIAGRAM FIGURE 3

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10 X 10 TO THE INCH MADE IN U.S.A.

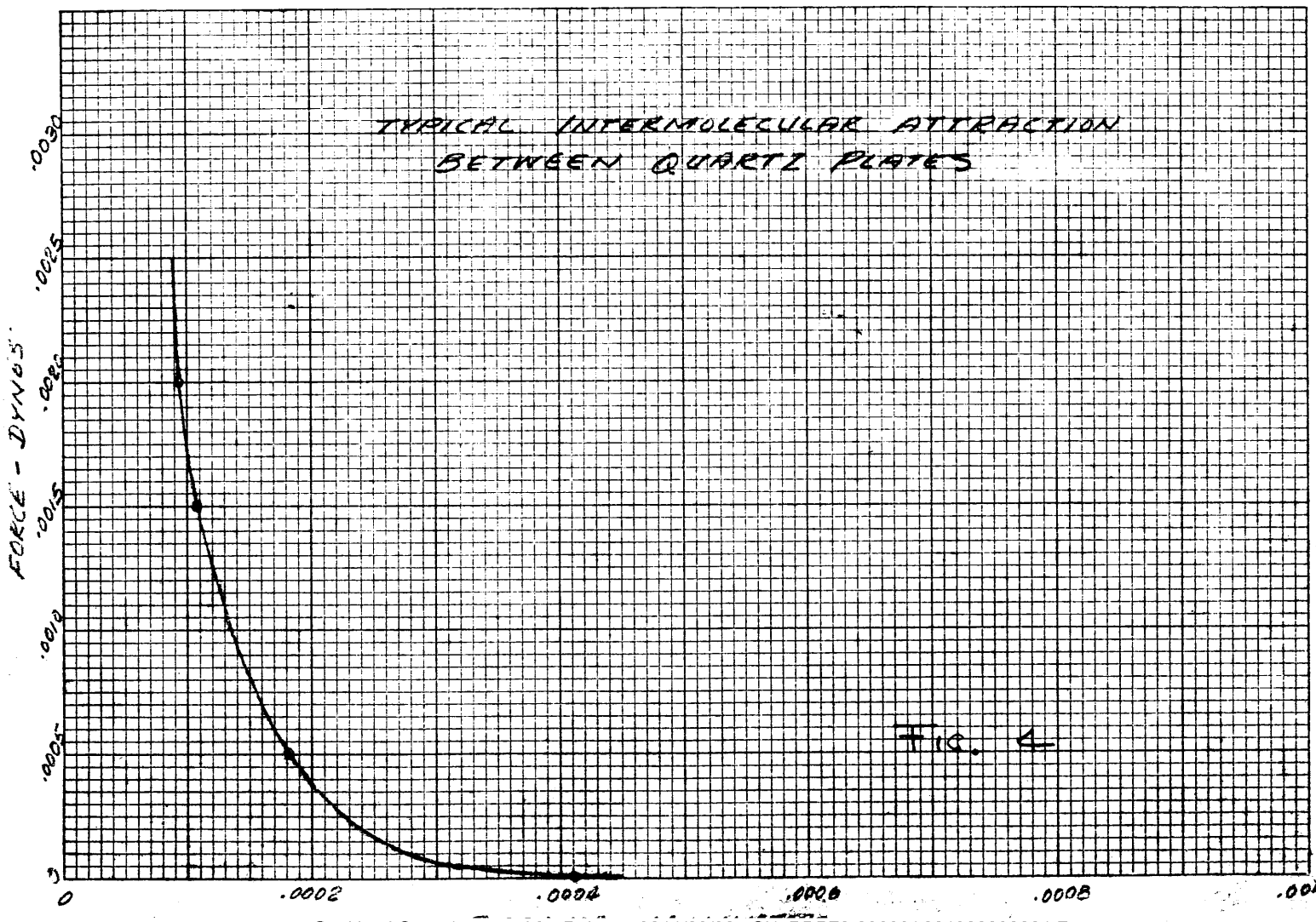

Fig. 4

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10 X 10 TO THE INCH MADE IN U. S. A.

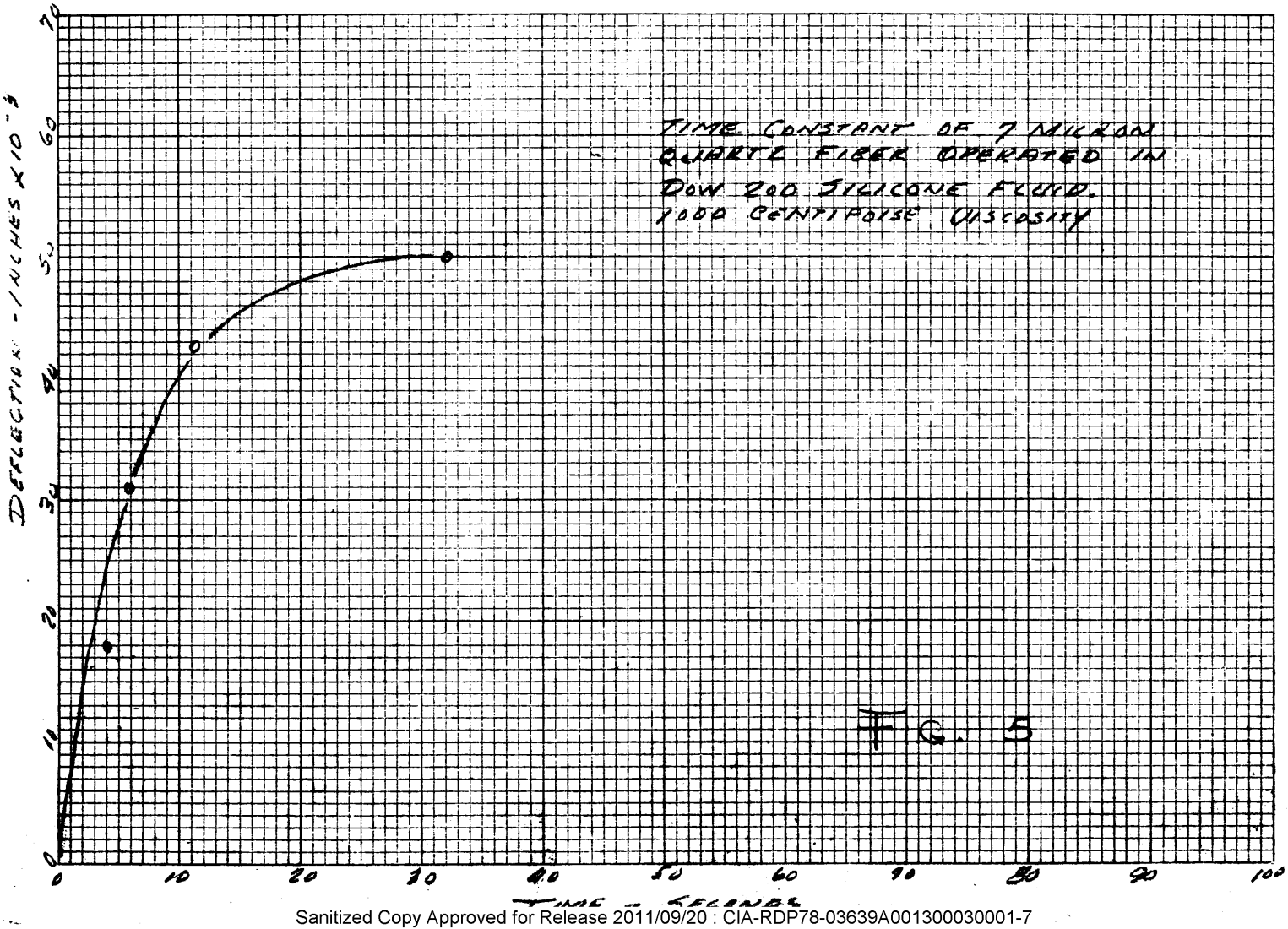

FIG. 5

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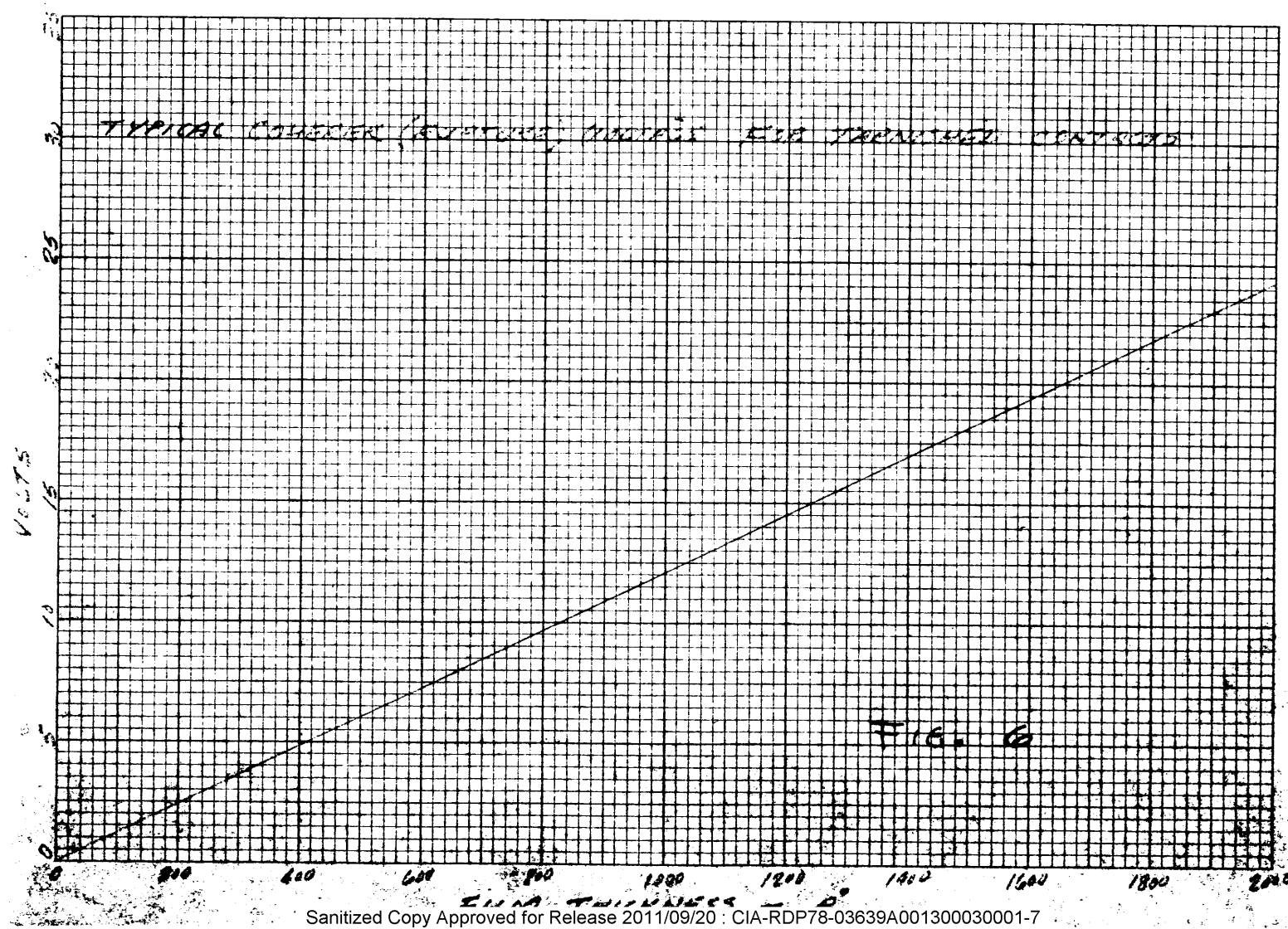

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10 X 10 TO THE INCH MADE IN U.S.A.

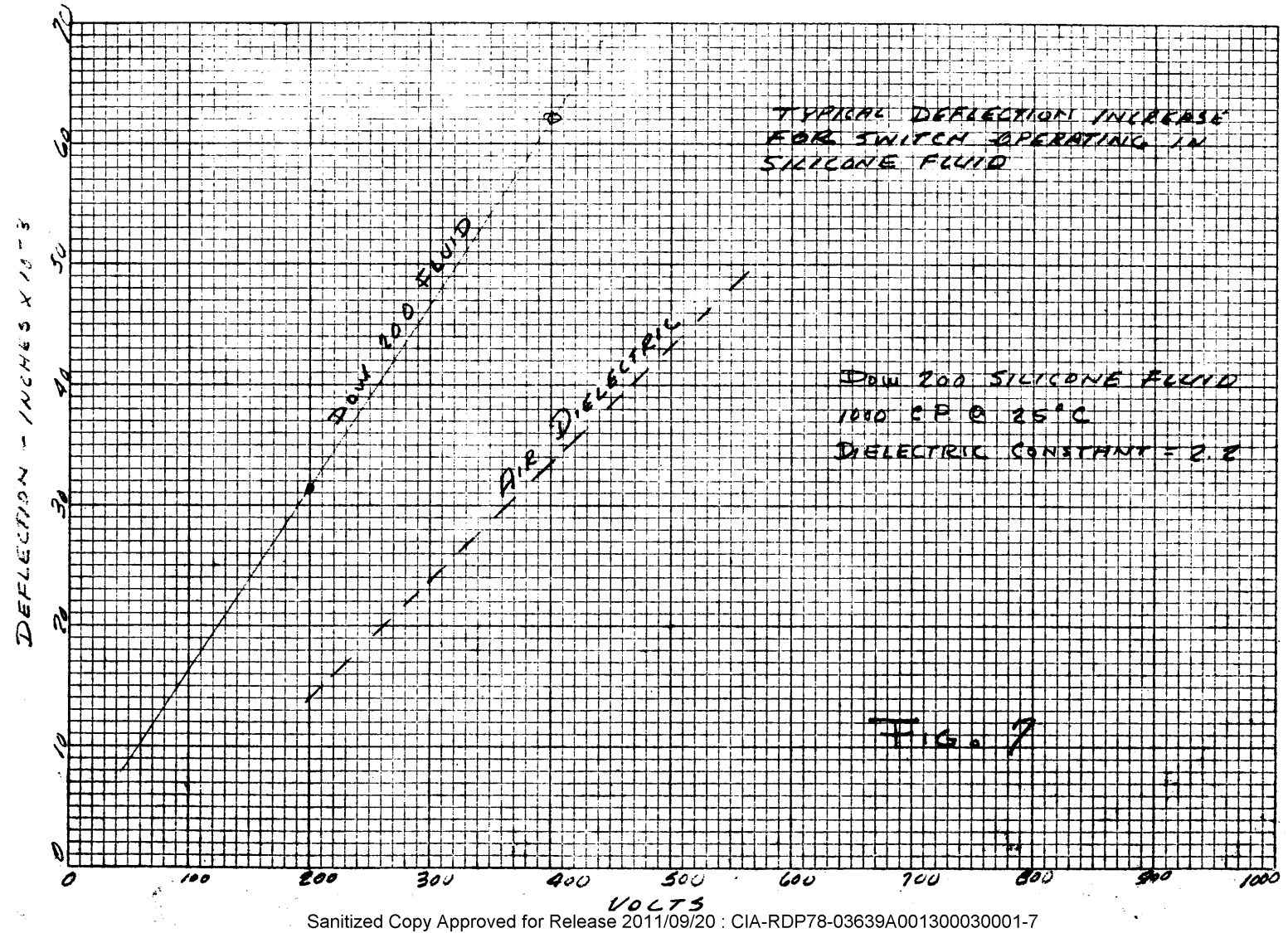

Fig. 7

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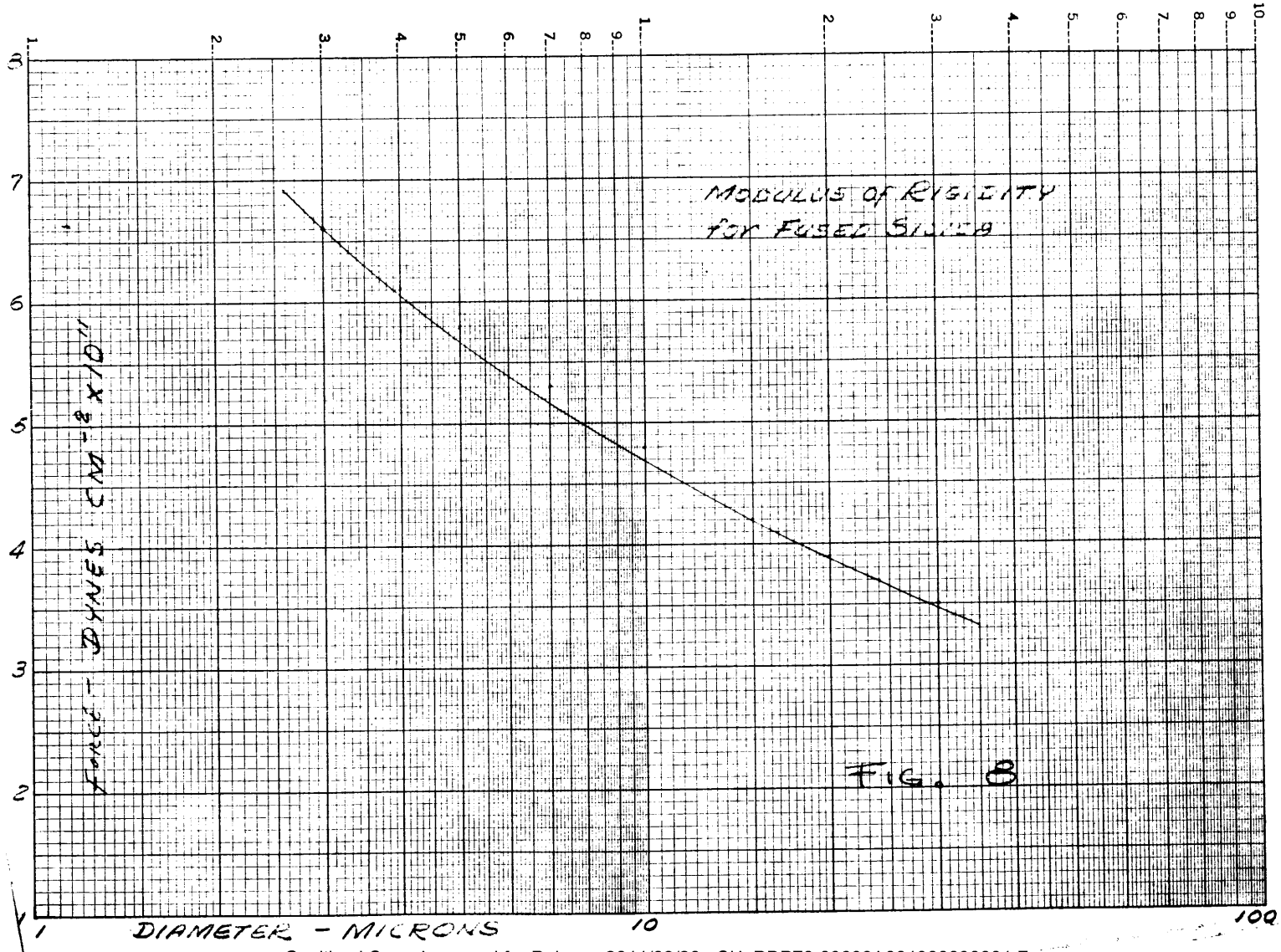

Fig. 8

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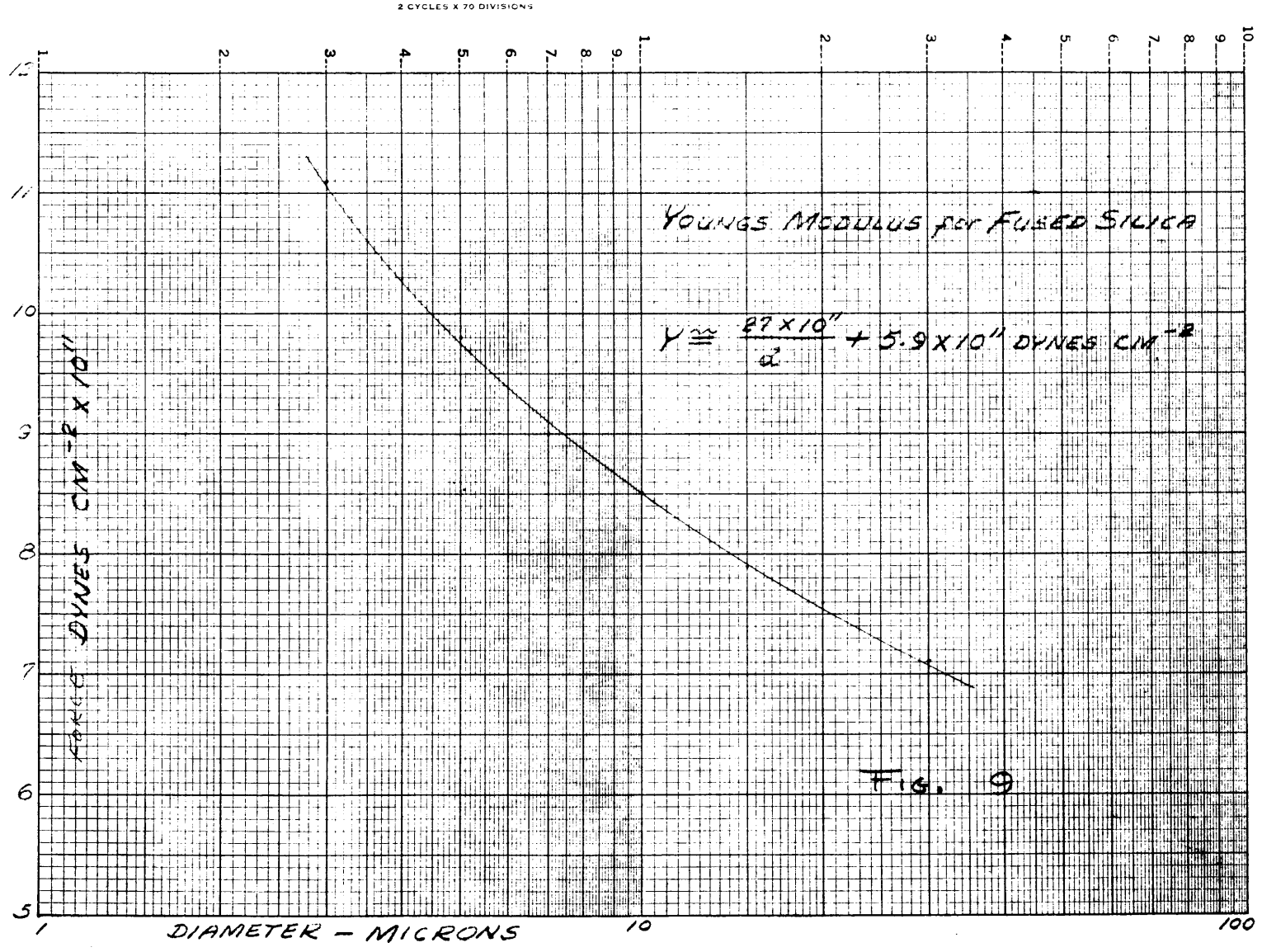
2 CYCLES X 70 DIVISIONS
FORCE DYNES CM-2 X 10^11
DIAMETER — MICRONS
YOUNGS MODULUS for FUSED SILICA
Y ≅ 27 X 10^11 / d² + 5.9 X 10^11 DYNES CM^-2
Fig. 9

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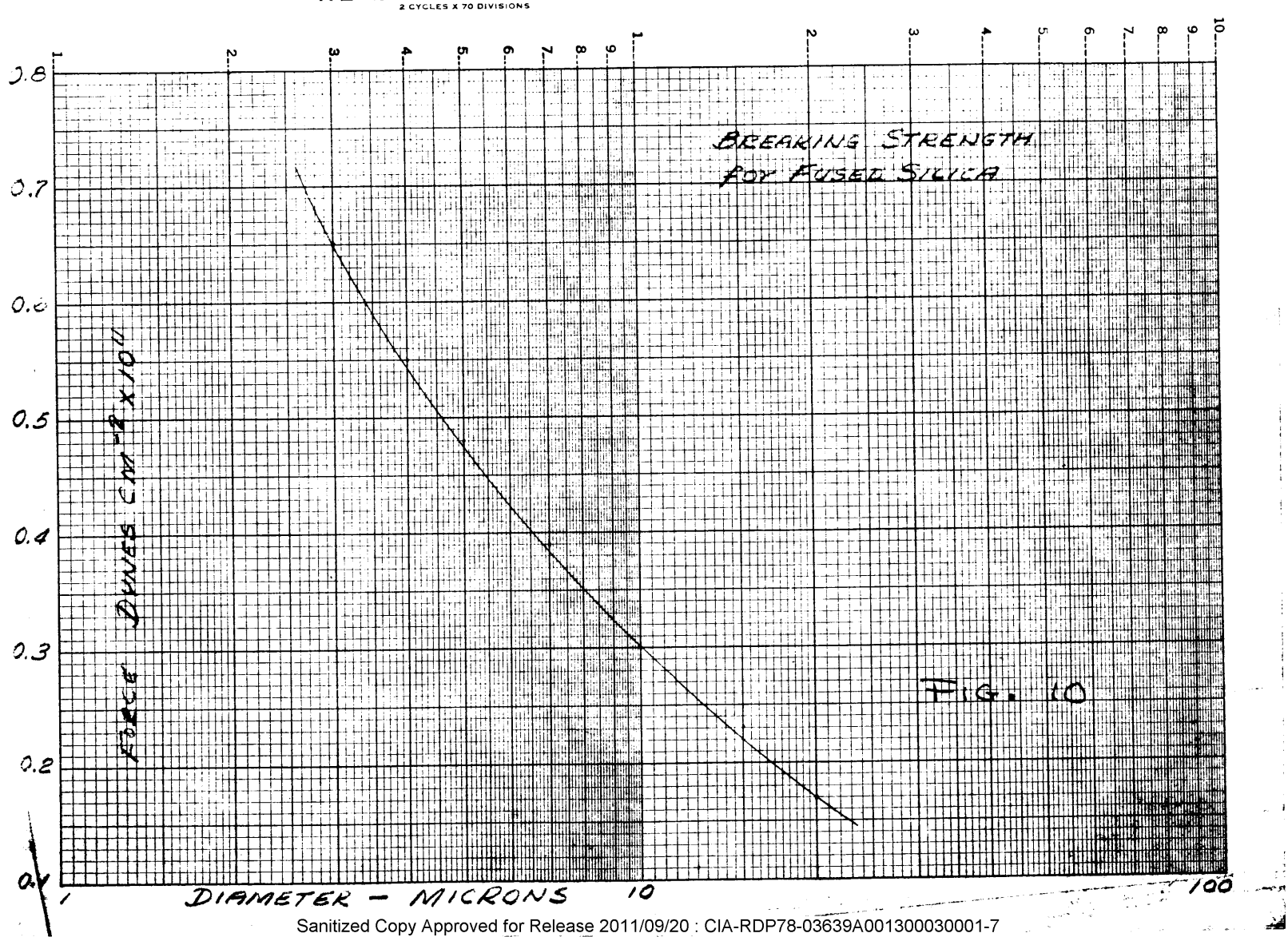

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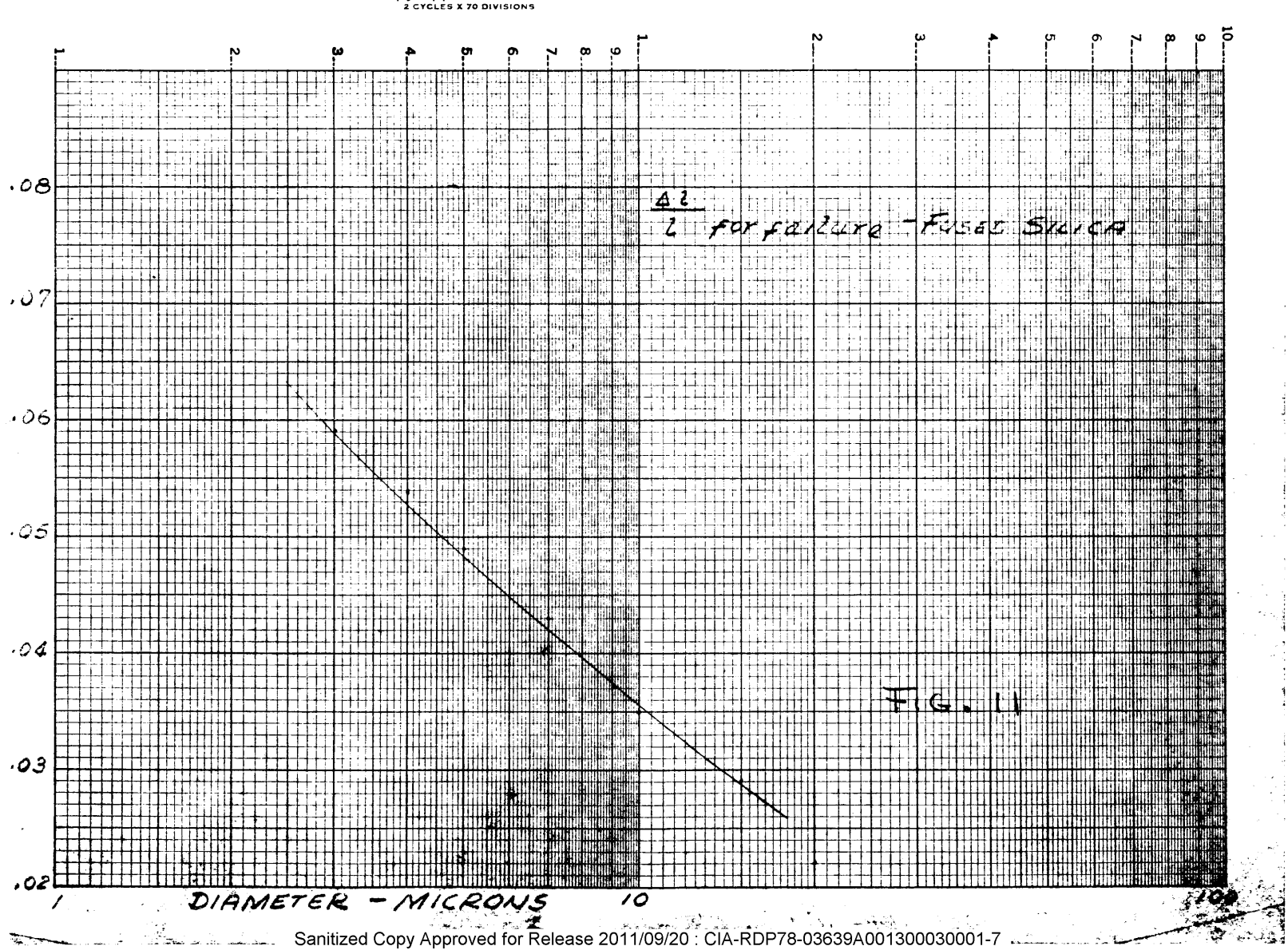

FIG. 11

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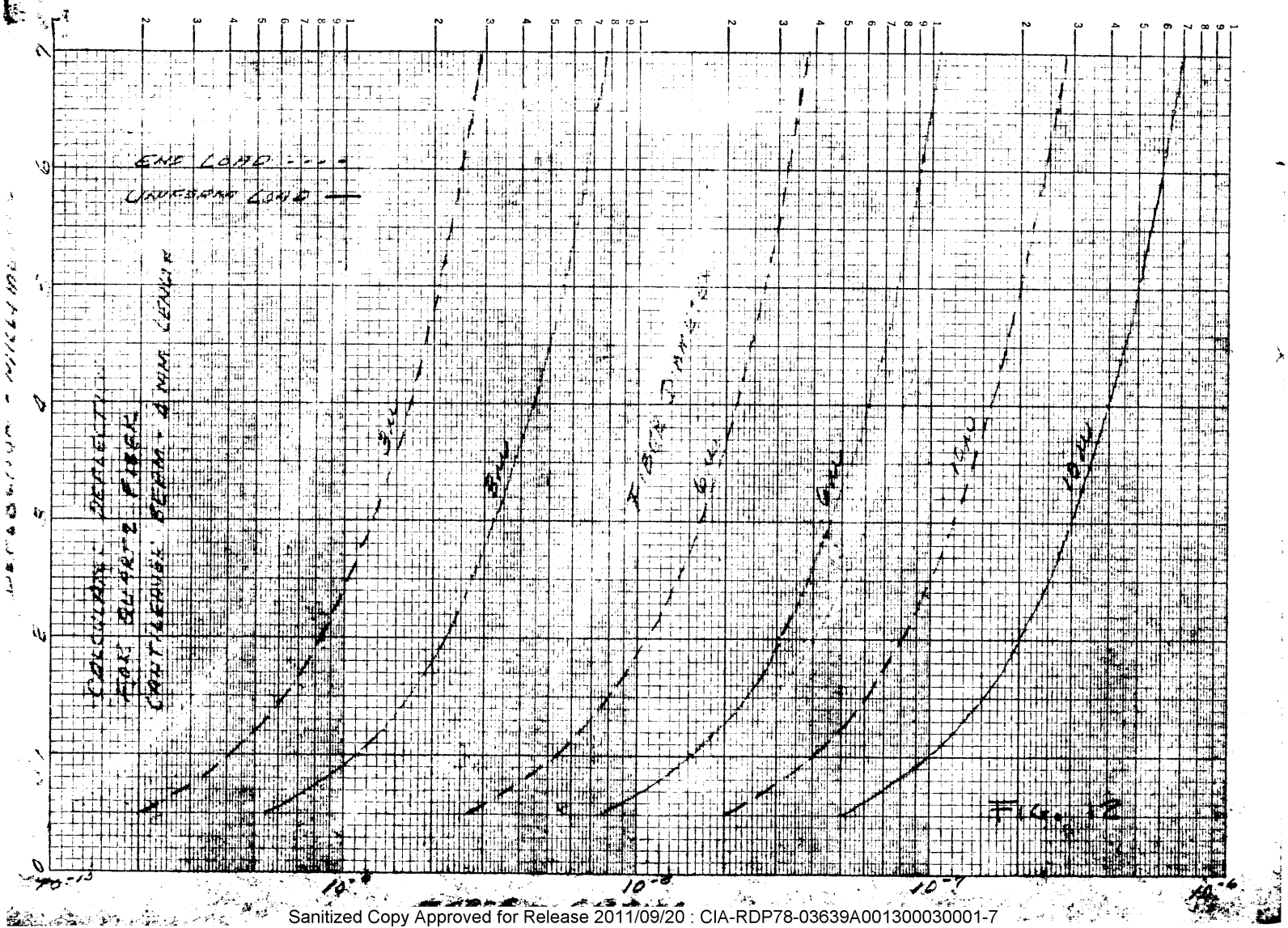
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



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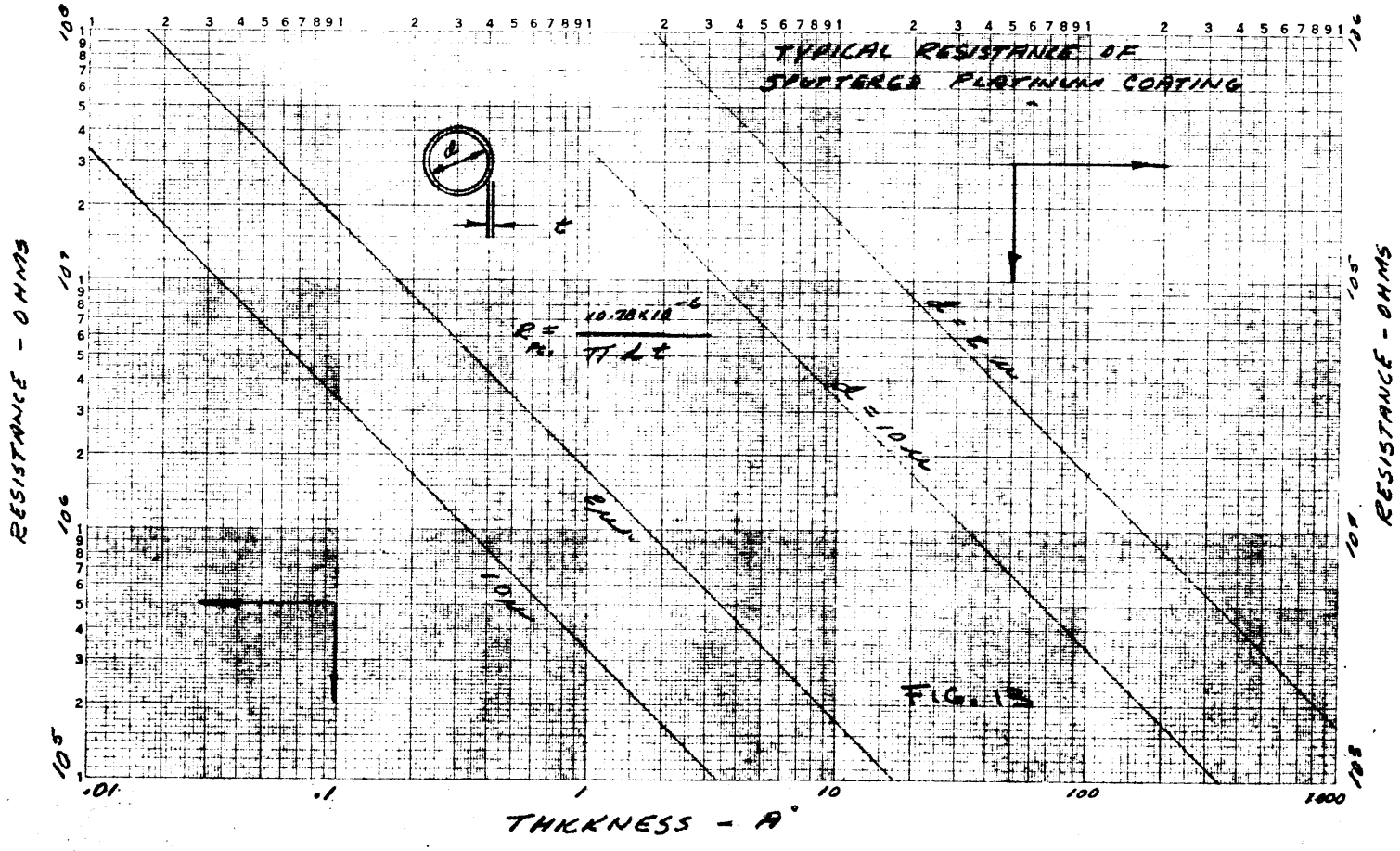

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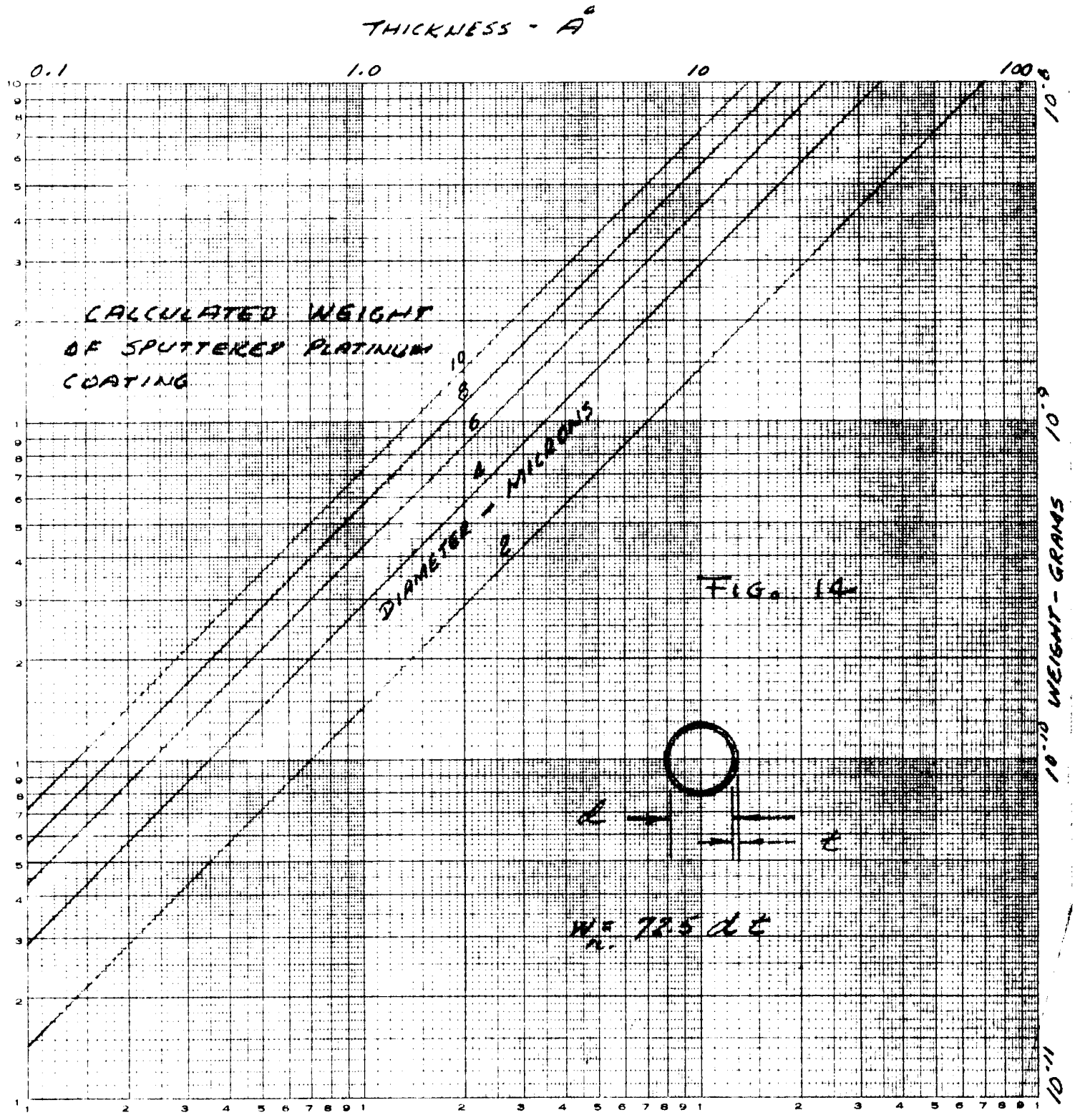

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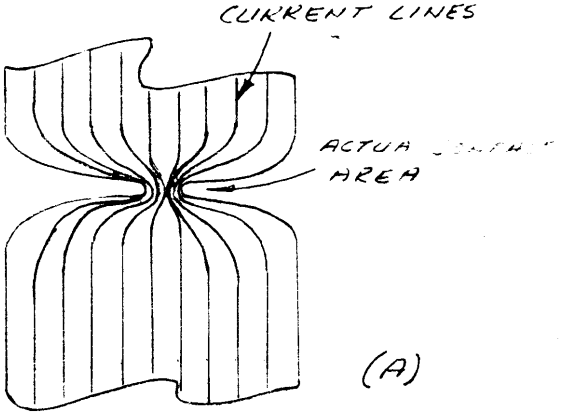
SPREADING RESISTANCE



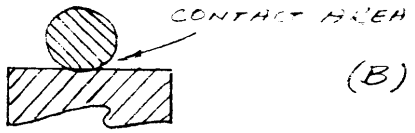
CONTACT CROSS SECTION

$$R_s = \rho / 2A \text{ OHM-CM.} \quad (1)$$

PRESSURE OF FLUIDITY FOR PLATINUM APROX. 65 KG/MM²

FIG. 15

TYPICAL CONTACT RESISTANCE



CONTACT CROSS SECTION

CONTACT AREA FOR ELASTIC DEFORMATION.

$$A = \sqrt[3]{\frac{3 W \eta R}{8 E}} \text{ CM}^2 \quad (2)$$

WHERE:

A = RADIUS OF CONTACT AREA
W = FORCE - GRAMS
η = 3 - 4
R = RADIUS OF SPHERE
E = YOUNGS MODULUS GR./CM²

COMBINING (1) & (2)

$$R_s = 0.45 \rho \sqrt[3]{\frac{E}{WR}}$$

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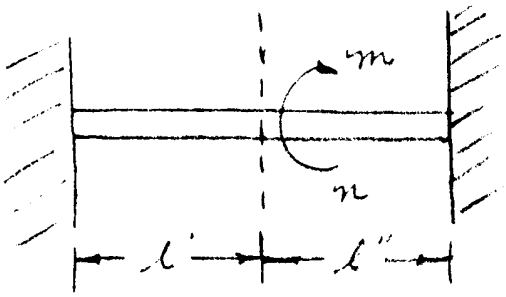
TORSION FIBER FIG. 16

FIBER DEFLECTION $$\phi = \frac{2lT}{\pi r^4 g} \qquad (1)$$

CONSIDER NOW!

THE TORSION FIBER IS STATIONARY AT BOTH ENDS AND SUBMITTED TO A TORQUE AT SOME INTERMEDIATE POINT OF CROSS SECTION m, n.



(A)

THEN: FOR BOTH PARTS OF THE FIBER THE ANGLE OF TWIST IS EQUAL. AND AS SHOWN BY (1) THE TWISTING MOMENTS ARE INVERSELY PROPORTIONAL TO THE LENGTH OF THE PARTS.

THEREFORE:

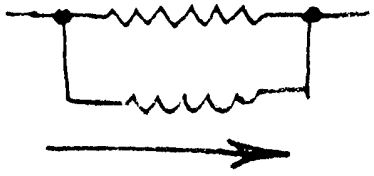
$$\phi = \frac{2T}{\pi r^4 g} \times \frac{l'l''}{l'+l''} \qquad (2)$$

WHICH: GIVES BY ANALOGY.

ELECTRICAL EQUIVALENT.

ROTATIONAL IMPEDANCES IN SERIES IS GIVEN BY ADMITTENCES IN PARALLEL

OR: $y = y_1 + y_2$ (3)



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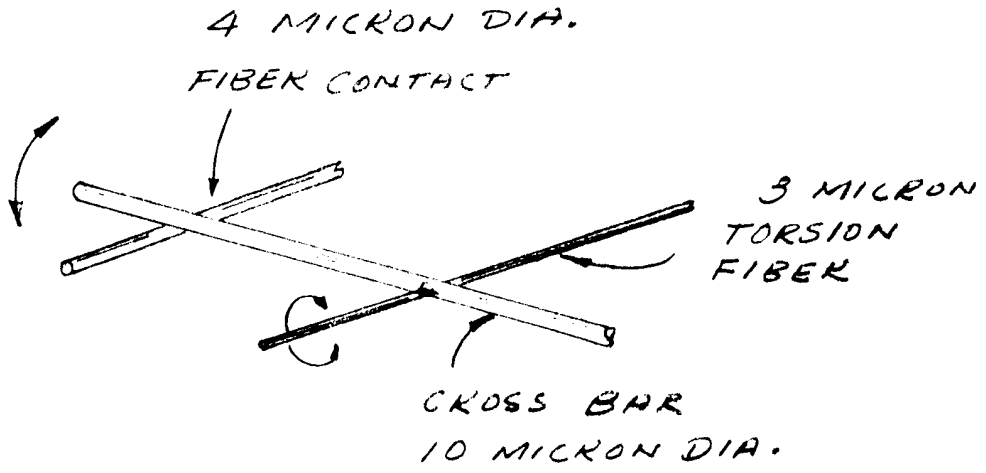
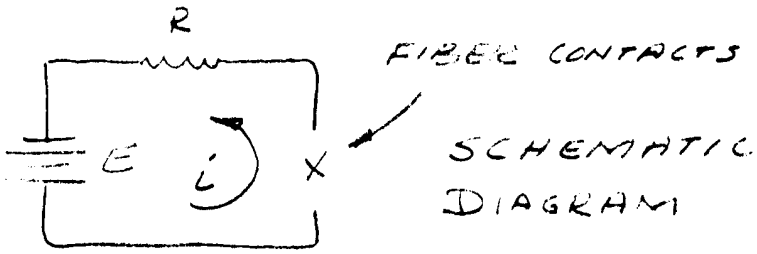
TYPICAL OPERATING CHARACTERISTICS OF QUARTZ FIBER CONTACTS

FIG. 17





E = 30 VOLTS

R = RESISTANCE OF FIBERS ≅ 1.2 MEGOHMS

i = 25 MICROAMPERES

SWITCH WAS OPERATED AS SHOWN FOR A TOTAL OF 1200 CYCLES WITHOUT FAILURE.

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